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GFRP bridge deck panel

M. Vovesný[a]* and T. Rotter[a]

[a]*CTU in Prague, Faculty of Civil Engineering, Department of Steel and Timber Structures, Thákurova 7, 166 29 Praha 6, Czech Republic*

Abstract

The aim of the research is design and analysis of new bridge deck panel made of glass fiber reinforced polymer (GFRP). Use of GFRP in construction is rapidly growing in last few years. The reason for use GFRP is its low self weight in compare of strength and high resistance against weather influenced degradation resulting in long life. Using GFRP for the construction of the bridge deck leads to lightweight construction that can pass the required wheel load. Lightweight design is appreciated for temporary bridge which is expected to be transported and assembled often on places of current need. Long durability and resistance against weather degradation also reduces maintenance costs of bridge deck. Design of deck panel will be done on the base of loading experiments and FEM analysis. The main use of GFRP bridge deck panel is for temporary bridge but it is possible to extend its use on permanent or movable bridges.

Keywords: GFRP, bridge deck, temporary bridge, FEM analysis, load tests

1. Introduction

The bridge deck is part of the bridge structure, which is at most often damaged by influence of weather and traffic on the bridge. For this reason is necessary to design the bridge deck because very carefully with regard to future maintenance costs during the lifecycle of the bridge structure. One way to achieve low maintenance costs over the life cycle is the usage of new durable materials. One of these materials is fibre reinforced plastics (FRP). This material is relatively new in civil engineering, but now is becoming more frequently used for constructions. The main reason to use this material is its high resistance to degradation by weathering in combination with low specific weight. In Comparison with conventional materials such as wood, steel or concrete the initial cost of FRP construction is still very high. But when maintenance cost is included the lifetime cost of FRP construction becomes comparable with constructions using conventional materials. One of

* Tel.: +420 224 353 876; fax: +420 233 337 466
Email address: martin.vovesny@fsv.cvut.cz

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the possibilities where the FRP may be conveniently applied is temporary bridge. Design of temporary structure is different from design of permanent structure. In the design of temporary structure it may occur at first sight hardly solvable problems because of the requirement for reduced weight for easy transportation but on other hand not to reduce bridge load capacity or service life. At present, the bridge deck is often made of timber wood that is light but is not able to fulfill requirement for long service life. It was necessary to restore often the deck structure to serve its purpose well. The aim of the FRP bridge deck panel development for temporary bridges is to create alternatives to the most commonly used timber deck and sweep away its main weakness, insufficient durability. Use of these FRP bridge deck panel should reduce maintains cost and could increase the load capacity of bridge deck whilst the bridge weight stays reasonably low.

2. Design of deck panel

2.1. Deck panel construction

Deck panel is fabricated by the manual joining of I-beams with top and bottom laminated panels. The cross section of deck panel and its dimensions are show in the Fig. 1. Length of deck panel is 1500 mm. These panel dimensions are design for temporary bridge “Těžká mostní souprava“(TMS).The design wheel load was 150 kN. Same design approach can be used to design deck panel suite different requirements on size and load capacity without large investments into manufacturing tools.

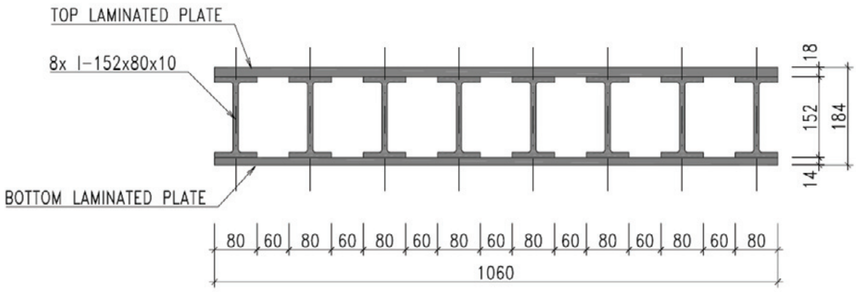

Fig. 1. Cross-section of deck panel

Used I-beam is of the shelf product which is manufactured by pultrusion. This is fully automatic technology which is able to achieve high reinforcement ratio up to 70 %. With handmade technology used for top and bottom plate is not possible to achieve same reinforcement ration as by fully automatic and well controlled pultrusion. Achievable up to 55 % is acceptable for the design purpose. This technology still allows good control of plate thickness and so the handmade plate has required strength. By handmade laminating different plates can be manufactured with very small investment into special production tools. Joint between the I-beams and laminated plates is made at the end of lamination process of the plate. When the last lamina is laid on the plate the I-beams are pressed into raw top layer of the plate matrix and then the matrix is hardened. This type of connection ensures interaction between the I-beam and laminated plates.

2.2. Material of deck panel

As it was say before all construction is fabricate of FRP material. This type of material consists of two basic parts, which each of them have specific function. The first part of material is polymeric matrix. For the manufacture of deck panel was chosen polyester, which has sufficient rigidity and resistance against degradation. The second parts of FRP material are reinforced fibers. With focus on the final cost of deck panel was chosen glass fibers reinforcement. These fibers have sufficient strength for deck panel construction. After consultation, with manufacturing company, were define the reinforcement ration and type of reinforcement.

I-beams are consisting of 47% of matrix and 53% of glass fiber reinforcement. Types of reinforcement was chosen as a combination of reinforcing strands which made up 51% of all the reinforcement and the remaining 49% consisted of mats of fibers with random orientation. Reinforcement of laminated plate is made of 37% percent of non-woven mat with random orientation of fibers and 63% are woven mats with fibers orientation in two perpendicular directions. Number of layers varies according to thickness of laminated plate.

2.3. Material properties tests

In order to design panel dimensions and analytically determine its loading capacity and deformation caused by the wheel load. It was necessary to determine the material properties of the FRP material. These properties were determined on the basis of the material tests. FRP testing procedure is described by a series of standards. For this research was chosen Standard ASTM D3039 [1] which details the test process under which material mechanical properties are determined. From panel were taken strips of material on which were conducted tensile tests. The aim of the test was to determine modulus of elasticity in tension and stress at material failure. Five samples from different parts of panel components were tested. Each was chosen so that all have different fibre orientation it was than possible to determine material properties is all main stress directions. Identification and dimensions of material samples are shown in Table 1.

Table 1. Position and orientation of samples

Number of sample	Position of sample	Orientation of the sample	Dimension [mm]
1	flange of I-beam	longitudinal direction	10x25x350
2	web of I-beam	longitudinal direction	10x25x350
3	flange of I-beam	traverse direction	10x25x250
4	laminated plate	longitudinal direction	20x25x350
5	laminated plate	traverse direction	20x25x350

On each sample were installed two strain gauges to measure relative strain. Measured values were used to calculate modulus if elasticity for each sample. Dependences of stress and strain in the samples are showed in Fig. 2 to Fig. 4.

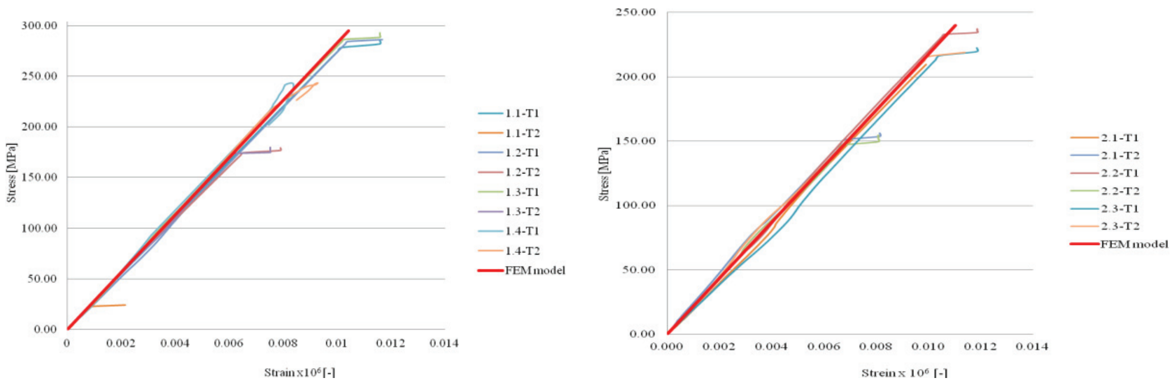

Fig. 2. (a) tensile test of sample 1.1 – 1.4; (b) tensile test of sample 2.1 – 2.3

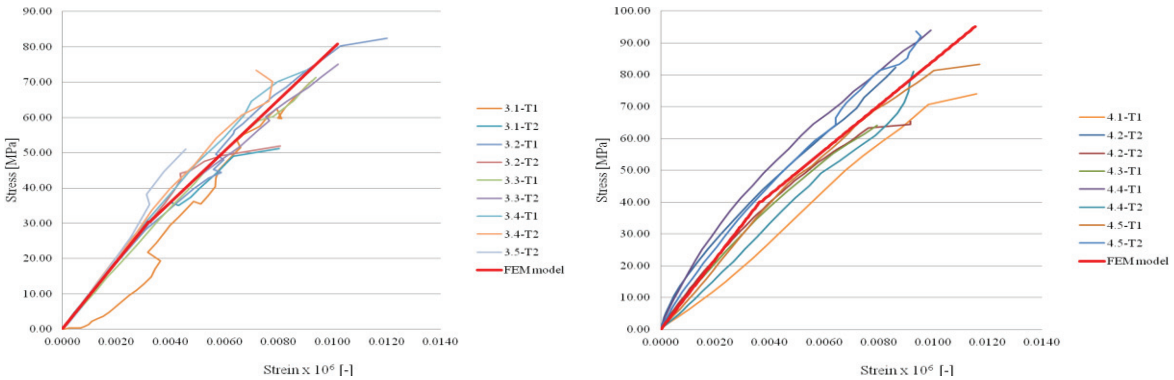

Fig. 3. (a) tensile test of sample 3.1 – 3.5; (b) tensile test of sample 4.1 – 4.5

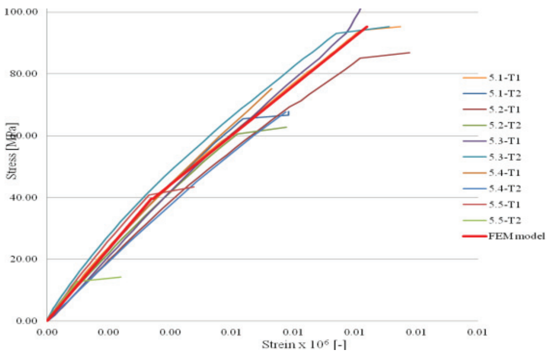

Fig. 4. tensile test of sample 5.1 – 5.5

Material properties gained from the testing are shown in Tables 2 average values were used for FEA analysis. Most cases the samples did not breached only by tension, but in damaged area occurs also delimitation of individual layers and slip of lamina. Table 2 lists the values of modulus of elasticity. In order to describe the behavior of samples 1 and 2 linear diagram of stress and strain was used. For samples 3-5 on which experiment resulted into damage of the sample was used bilinear stress-strain diagram with definition of limit of elasticity.

Table 2. Material model and modulus of elasticity

Number of sample	Material model	Limit of plasticity	Modulus of elasticity	
		R_e	E_1	E_2
	[-]	[MPa]	[MPa]	[MPa]
1.1 - 1.5	linear	-	28250	-
2.1 - 2.3	linear	-	21750	
3.1 - 3.5	bi-linear	30	9500	7250
4.1 - 4.5	bi-linear	40	11000	7000
5.1 - 5.5	bi-linear	40	11650	8000

2.4. FEM analysis of bridge deck panel

Numerical analysis of the panel was performed in the FEM software ABAQUS. Aim of the analysis was to determine the stress in the panel and the deflection by the design load. As the design load was used wheel load 150 kN acting on the area of 250x250 mm. The load was determined according to ČSN EN 1991-2. In order to achieve better consistency with the real situation the wheel load [2] was spread at larger area which is according to standards 400x400 mm.

The numerical model was composed of elements type C3D8 Brick: An 8-node linear brick. The size of brick was 20 mm. The connection between I-beams and top and bottom plates was model as a "tie" contact which is used for modeling of fully rigid connections which directly transmits all stress between booth connected elements without any slipping. For the deformation analysis the panel was placed on two a perfectly rigid supports on which he was allowed to rotate and slip to simulate real conditions. It is expected that the panel will be on the bridge structure loosely placed on steel cross girder.

The results of numerical analysis showed that the maximum stress in the panel´s elements does not exceed in any way failure values of stress which were determined from material experiments. The maximum stress reached in I-beam was 42 MPa stress in the top plate was 35 MPa and 29 MPa, bottom plate. The stress value was given as a max Misses value of stress.

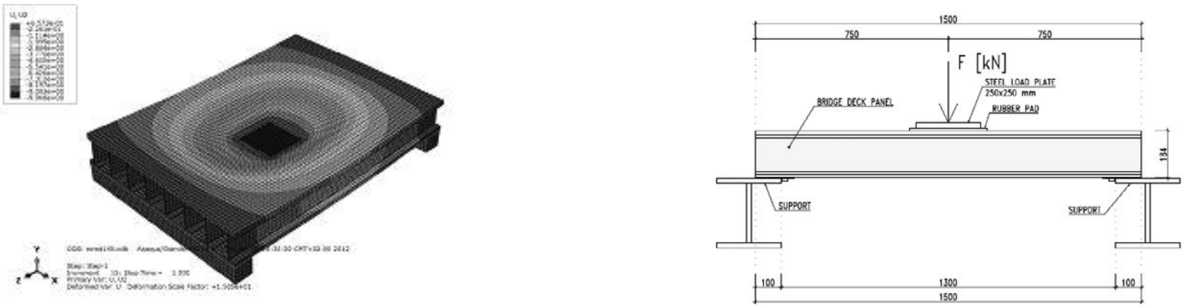

Fig. 5. (a) FEM model of deck panel – deflection by wheel load 150 kN; (b) configuration load test experiment

3. Load test of deck panel

To test the panel behaviour under wheel load and to verify FEM model load tests were carried out on two samples of bridge deck panels. Configuration of load tests is show in Fig. 8. For these load tests strain gauges were installed on different places of the panels to measure the relative deformation of the panel. Strain gauges were installed on the inner side of the I-beam flanges and in the longitudinal direction in the middle of the top and bottom plate above the axis of each I-beam, orientation of all strain gages was in the longitudinal direction of the panel. Other strain gages were installed on the bottom plate between each I-beam orientation of these gages was in the transverse direction. Used strain gauges were 1-LY41-20/120. Deflection of deck panel was measured under each I-beam.

Each panel was loaded with 50 kN on the edge of the panel, see Fig. 6a than the load path was moved to the centre of the panel see Fig. 6b. Panel was loaded with force of 50 kN, 100 kN and 150 kN after each load step the deck was panel unload. After completion of the loading cycle panel was loaded with controlled displacement up to failure.

Fig. 6. (a) load test of deck panel path on the edge of deck panel; (b) load test of deck panel path in the middle of deck panel

Maximum load at the moment of panel destruction was 300 kN. The breach of deck panel has occurred when limit strength in pressure was reached in I-beam wall under the load plate. The second sample has failed under the load of 260 kN. The breach occurs when limit shear strength limit was reached in the connection between the wall and flange. Measured strain curves were compared with results of numerical analysis, see Fig. 7. Plots on Fig. 7 show panels deformation in transverse section through the centre of the panel. The comparison showed very good compliance of predicted and measured deflection.

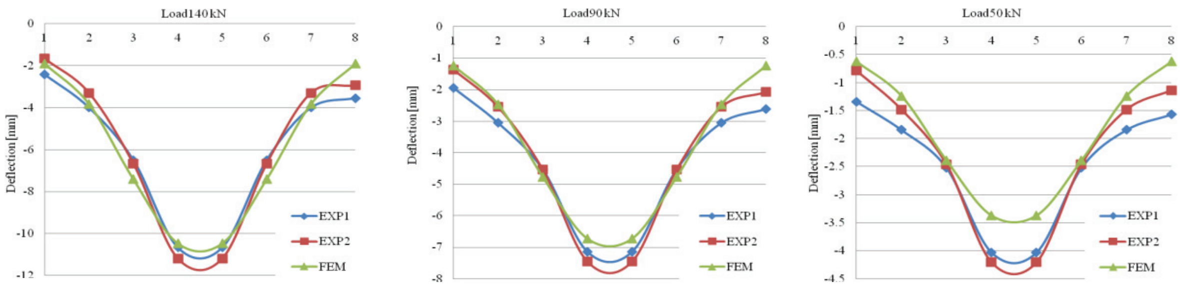

Fig. 7. comparision of results tensile test and FEM model

4. Conclusion

Numerical analysis and physical tests carried out on designed deck panel proved that this type of deck panel has sufficient strength to be used for construction of temporary bridges. In the future tests will be prepared to demonstrate sufficient structural durability under cyclic loading that occurs during service life of the construction.

Acknowledgements

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